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GWILYM E. OWEN

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IN PHYSICS

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THE DEGREE OF DOCTOR OF PHILOSOPHY

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DIELECTRIC LOSSES AT HIGH FREQUENCIES

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Abstract

Description of calorimetric method and measurements of the power-loss in small pieces of dielectrics at high frequencies.—The power loss in very small pieces of dielectrics in high frequency alternating fields is measured by a calorimetric method in which the heat produced in the dielectric is compared with that produced in a resistor carrying a measured direct current. For vulcanized fibre, celluloid, rubber dam and glass the loss is found to be proportional to the frequency and to the square of the applied voltage.

THE customary methods of measuring dielectric losses at high frequency, include: (a) balanced-bridge methods; (b) electrostatic wattmeter; (c) resistance-variation method; and (d) substitution, or direct-comparison methods. In using any of these, there are difficulties, due to the assumptions that must be made. In any bridge method there are resistances and inductances whose variation with frequency is not easily determined. If an electrometer is used as an electrostatic wattmeter, a resistance is needed which should be (and probably never is) non-inductive. Likewise in a resistance-variation method, the resistance of the circuit excluding the condenser must be assumed negligible at all frequencies. In the substitution method, losses in the standard air-condenser are neglected. A method which depends upon the amount of heat generated in the condenser would seem to be clear of these difficulties. I have measured dielectric losses in gray vulcanized fibre, celluloid, dental rubber dam, and glass, by means of a differential calorimeter. This method needs no assumptions about any electrical property of the circuit and it measures only the energy transformed into heat in the condenser. It has the advantage of being applicable to small condensers which are difficult to measure by any other means.

Apparatus

Two similar two-ounce bottles, A and B (Fig. 1) are connected together through glass tubing and a specially designed manometer P, and are sealed with paraffin at atmospheric pressure. B contains a small condenser C of the substance under test and a resistor R on separate leads. The other bottle is used merely as a pressure balance to avoid the effects of external temperature and barometric changes.

The manometer consists of a circular brass case divided into two parts and flanged, so they can be fastened together with screws. A diaphragm is fastened with shellac to the projecting ring N, and the two parts are then

screwed together. Another projecting ring E, stretches the diaphragm tightly. An arm L has one end fastened to the middle of the diaphragm and the other pinned to a small rotating support for the mirror M. Good paper, thoroughly impregnated with stop-cock grease, makes a good diaphragm. Readings are taken by projecting a beam of light through the walls of the tube against the mirror, and reading the position of the reflected beam on a scale, as shown in Fig. 1. No difficulties are encountered due to distortion by the cylindrical glass walls if the plane of the mirror is approximately perpendicular to the axis of the tube.

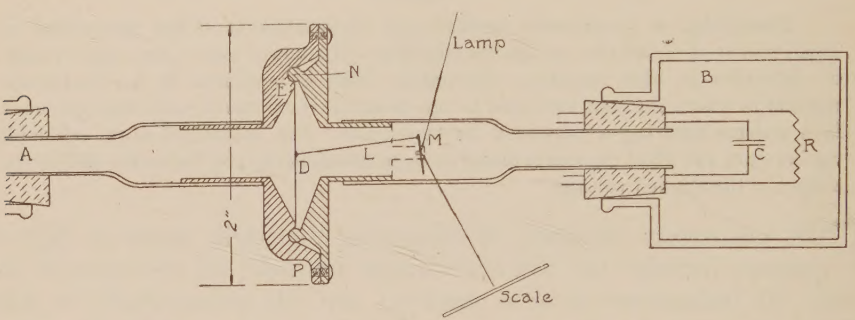

Fig. 1. Apparatus. A and B, 2-oz bottles; R, resistance; C, test condenser; M, mirror; D, diaphragm.

The electrical circuit consists of a Hartley oscillator, and a pick-up circuit made up of a coil of about 50 turns of wire across a variable air condenser in parallel with the test condenser. The pick-up coil can be moved with respect to the oscillating circuit by a slow-motion screw to obtain any desired voltage on the test condenser. The frequencies are measured with a General Radio Company wavemeter type 174B., and the voltage across the test condenser with an electrostatic voltmeter. An attempt was made to use a vacuum-tube peak-voltmeter such as is described in Van der Bijl "Thermionic Vacuum Tube," page 367, but it did not give readings which were independent of frequency. A comparison with the electrostatic voltmeter showed that at high frequencies, the tube voltmeter was entirely unreliable.

Method

When an oscillating current passes through the test condenser the heat produced in it changes the pressure of the air in bottle B. The pressure rises to a steady state, when the heat generated in the condenser is equal to that dissipated from the walls of the bottle. The deflection of the manometer beam is then noted. Afterwards the same pressure change is produced by passing a direct current through the resistor R and measuring the applied voltage with a potentiometer. The power dissipated in the condenser is then equal to that in the resistor. In practice, a curve is plotted between power used in the resistor and deflection produced. This serves

as a calibration curve for the instrument but it must be recalibrated every day. Within the range used, this curve is a straight line.

Results

Figure 2 shows the results obtained for a gray vulcanized fibre condenser 1 cm square and 0.03 cm thick, with zinc electrodes sprayed on by the Schoop pistol process. (This gives much more intimate contact between metal and dielectric than any other process available for hygroscopic materials.) The curve marked with circles is the calibration curve. It does not pass through the origin because of a slight uncertainty in the zero reading of the pressure guage. This uncertainty exists in every reading but does not affect in any way the relative values of the readings. In order to get an idea of the power-

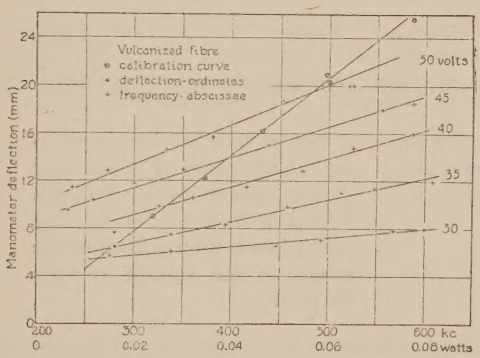

Fig. 2. Curves showing variation of dielectric losses with frequency in dry vulcanized fibre. The circles show deflection of manometer plotted against power loss in the resistor. The crosses show deflection plotted against frequency in kilocycles at various voltages. The deflections are proportional to the frequency in each case, except for the doubt due to the two points on the 50-volt curve.

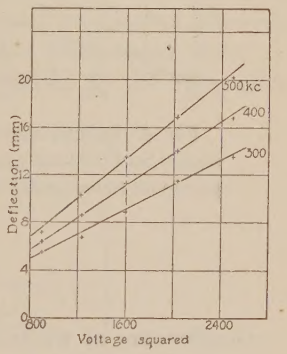

Fig. 3. Deflections plotted against voltage-squared for dry fibre. The loss is proportional to the voltage squared. Points taken from curves of Fig. 2

loss involved, we see that at 40 volts and 350 kilocycles, there is a deflection of 10 mm which is equivalent to 0.028 watts as is shown by the calibration curve. For frequencies ranging from 225 kilocycles to 600 kilocycles the power-loss is directly proportional to the frequency for voltages up to 50 volts, i.e., field intensities up to about 1700 volts per centimeter; above which the results are not consistent. This inconsistency seems to be due to some property of the condenser, as it was found in rubber and celluloid but at different voltages. The dielectric loss is proportional to the square of the voltage for all frequencies in the range tested. This is shown in the curves of Fig. 3, whose points were taken directly from Fig. 2.

The presence of moisture has a very large effect. A condenser kept in an atmosphere of about 70 percent relative humidity over night showed twice as much loss as a similar one kept for two days in a bottle containing

a little phosphorus pentoxide. The condenser which gave the curves used in this article had been kept in a sealed bottle containing phosphorus pentoxide for over two months. For several weeks there was a noticeable decrease in the deflections, indicating that the drying-up process may extend over a long period of time. A condenser kept in a bottle containing a few drops of water gave very large deflections which were not reproducible.

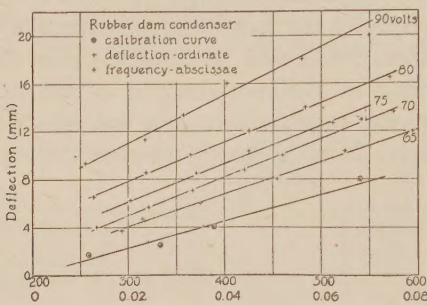

Fig. 4. Rubber dam condenser, 2.5 cm square and 0.03 cm thick. The loss is proportional to frequency up to 90-volt curve.

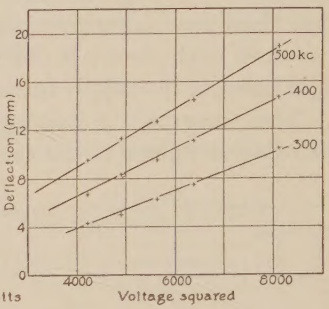

Fig. 5. Rubber dam condenser. Deflections of manometer plotted against voltage squared. Points taken from Fig. 4. The power loss is proportional to the square of the voltage at each frequency.

Condensers of white celluloid and dental rubber dam were tested with results which may be summarized as follows. For all voltages which gave consistent readings, the losses bear a linear relation to the frequency and vary as the square of the voltage. The readings for celluloid become incon-

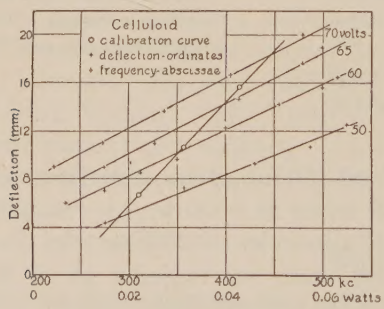

Fig. 6. Celluloid. The loss is proportional to the frequency up to 70 volts for a celluloid condenser 2 cm square and 0.03 cm thick.

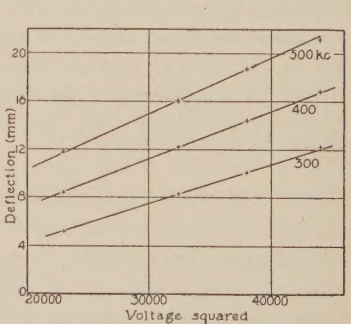

Fig. 7. Celluloid condenser. Deflections plotted against the voltage squared. The power loss is proportional to the square of the voltage.

sistent at about 200 volts, i.e., about 7000 volts per centimeter and for rubber at about 90 volts or 3000 volts per centimeter. A small microscope coverglass used as a condenser showed losses proportional to the frequency at

about 250 volts. Higher voltages were not available but the work will be continued on this and on clear fused quartz which also has been found to have a measurable loss.

Comparison of Results with Previous Work

It is not easy to compare these results with those of others, because most of the work done at high frequencies has been reported in terms of the power-factor of the condenser. It is generally accepted that the ratio S/cp is equivalent to the power-factor, where S is the conductivity of the dielectric at the frequency used, c is the capacity and p the frequency. But every term in this expression depends on the frequency and therefore the curves plotted between power-factor and frequency are not simple in form. Dr. G. E. Bairsto[1] has measured the conductivity of a variety of substances and finds, in most cases, one or two maxima in the curves plotted between conductivity and frequency. My results on similar substances show no evidence of such maxima. DuBois[2] finds the loss varies as the frequency

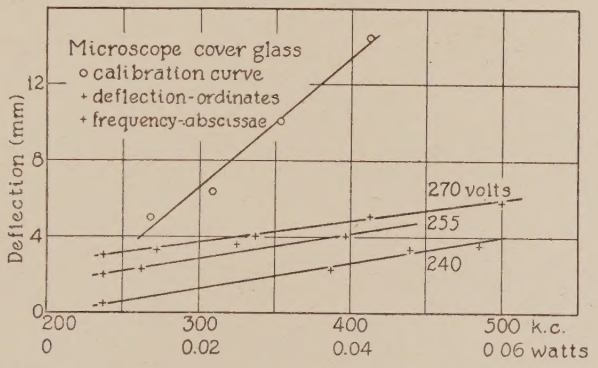

Fig. 8. Shows how the manometer deflection varies with frequency for a condenser made from a small microscope cover glass. The deflections are very small but seem to bear a linear relation to the frequency.

for low moisture content. While several observers have reported that dielectric losses in many insulators are proportional to the square of the voltage, the results of C. A. Butman[3] at low frequencies do not lead to that conclusion. Also James Mould[4] reports, "Energy dissipation varies as some power of the electric force which is greater than the square. The exponent varies greatly but is always greater than two." He also reports that in so-called "good insulators" the exponent varies greatly from two.

My results show the loss porportional to the square of the voltage up to a certain voltage for each material. It is possible that some change takes place in the dielectric or in the nature of the discharge through it, near voltages at which my results become inconsistent.

[1] G. E. Bairsto, Proc. Roy. Soc. London, **96**, 363 (1919).
[2] D. DuBois, J. A.I.E.E., page 689 (1922).
[3] C. A. Butman, Electrical World, **71**, 502 (1918).
[4] James Mould, Beama, June, 1923.

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